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The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy

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ABSTRACT

To meet global climate goals an energy transition is needed. However, energy transitions are complex and long-term processes and require a variety of public policy interventions to steer their direction and speed to achieve global climate change mitigation targets. One area where policy support is required is energy efficiency, which offers a high potential for carbon savings. It is widely acknowledged that energy efficiency improvements will need to be faster and deeper than is currently the case and this requires policy instrument mixes to support both those energy efficiency measures that are simple and cost-effective as well as more complex and costly technologies. In other words, policy mixes need to be well-targeted and comprehensive. In this paper, we address the issue of comprehensiveness in terms of technology-specificity and the level of complexity and costliness of energy efficiency measures. We use an existing dataset produced as part of a pan-European effort to understand instrument mixes in 14 EU Member States in the area of energy efficiency. Based on the empirical analysis and our segmentation of instrument types and their role in the overall mix, we illustrate the need for using a comprehensive instrument mix rather than single instruments.

1. Introduction

In order to reach the pledges made under the Paris Agreement on climate change it is clear that we need an ambitious energy transition towards low-carbon solutions involving every part of the economy [1]. Energy transitions, defined as structural change in the way energy services are delivered and used, are inherently complex, uncertain and difficult to govern, and there is wide ranging agreement that a variety of different policy instruments are needed to foster such transitions [2,3]. In this context, it is increasingly acknowledged that policy mixes are required to address the various market and system failures associated with sustainability transitions [4,5] (Jacobsson et al. this issue). However, most policy mix studies only cover a discussion of different instruments and their interactions, whereas a broader perspective would also include policy processes and policy mix characteristics [6,4]. In this paper, we focus on comprehensiveness as one key policy mix characteristics, but to analyse this in sufficient detail we limit our discussion to instrument mixes for which we propose a novel operationalisation of comprehensiveness. That is, while we recognize that the politics of policy making and implementation are a key factor in understanding the characteristics of real-world policy mixes, such a broader policy mix perspective is outside the scope of our study.

The emerging literature on the importance of policy mixes to tackle the decarbonisation of the energy system draws on different bodies of literature. These range from policy studies [7–9] to environmental economics [10] [55] and innovation and transition studies [2,4,11]. One focal area of such studies has been the interactions of different policy instruments, both between policy instruments in specific policy sub-domains, such as energy efficiency policy (e.g. [12]), and between sub-domains, such renewable energy policy and climate policy [54]. In contrast, studies in the policy design field have traced the development of policy mixes over time (e.g. [13] for building efficiency in the UK and Finland). Finally, transition studies have started to pay greater attention to the co-evolution of policy mixes and system innovation, such as for the case of technological innovation systems (e.g. [14] for offshore wind in Germany).

Research on policy mixes is also increasingly paying attention to the characteristics of policy mixes, although following different literatures with differences in terminology [15]. For example, policy design scholars have been using consistency, coherence and congruence as criteria to assess policy mixes in terms of the alignment of instruments and goals [9]. Drawing on contributions from different bodies of

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literature based in environmental economics, innovation and policy studies, Rogge and Reichardt [4] have proposed an initial set of core policy mix characteristics which include the consistency of instrument mixes and policy strategies, the coherence of policy making and implementation processes, as well as the credibility and comprehensiveness of policy mixes. Initial qualitative evidence for offshore wind in Germany suggests that these policy mix characteristics play a key role for corporate innovation activities [16].

In this paper, we focus on the comprehensiveness of instrument mixes, thereby analysing how extensive and exhaustive a mix is [36; p. 1627]. One way of operationalising the idea of comprehensiveness is by determining if the instrument mix includes technology push, demand pull and systemic instruments [17,18]. It has also been suggested that comprehensiveness could be assessed according to the degree to which it addresses relevant failures and barriers [4,5] ([57,59]). Here, we contribute to this literature by proposing a novel way of operationalising the comprehensiveness of instrument mixes, specifically in the context of energy transitions. More specifically, and following earlier suggestions by Rogge and Reichardt [15], we argue that comprehensiveness of instrument mixes within specific policy sub-domains should also be assessed regarding technology/technological specificity, instrument types covered, and sector(s) addressed. We argue that especially understanding the technological specificity of instruments in the mix is a precondition for designing effective instrument mixes that support the full range of low-carbon solutions needed to achieve an ambitious energy transition, including low-cost and simple energy efficiency measures as well as high-cost and complex options. Against this background, in this paper we investigate how certain instruments within the mix consider complexity and technology cost.

Empirically, our paper focuses on energy efficiency policy because a key part of the energy transition will need to be delivered by improvements in energy efficiency, as acknowledged in decarbonisation scenarios by the International Energy Agency [1]. However, it has long been established that even cost-effective energy efficiency measures are often not taken up by consumers or businesses (the so-called ‘energy efficiency gap’), and that therefore policy is needed to support their delivery [19–21]. In order to achieve the low-carbon pathways set out by the Paris Agreement and also at European and national level, the current uptake and ambition of energy efficiency improvements needs to improve significantly and much deeper and rapid decrease in energy use than is currently the case is required. A good example are buildings where current levels of low-carbon retrofits are far behind of what they need to be [22]. This means that policy needs to avoid just focusing on the easiest energy efficiency improvements (typically those with the lowest cost and easy to implement, e.g. loft insulation and energy efficient appliances and lighting) but also support more complex and costly solutions (such as industrial process optimisation and whole-house retrofits). We argue that such a step-change in a wide range of energy efficiency measures cannot be achieved through a single policy instrument. Instead, we argue that a well-targeted and comprehensive instrument mix is needed – something that so far has been neglected in existing studies on energy efficiency policy mixes (e.g. [13,12]).

In the remainder of the paper we first discuss the need for instrument mix analyses looking at technology specificity within the context of energy transitions and develop our analytical approach to assess comprehensiveness (Section 2). We then present the methodology employed to empirically investigate the variation within instrument mixes regarding the technological focus of instruments (Section 2). This is followed by a short overview of European energy efficiency policy provided in Section 4. In our results Section 5 we demonstrate empirically that different instrument types support quite different technologies with some variation across the different sectors (such as residential, service (including public), industry, and transport). We close the paper by providing concluding comments in Section 6.

2. Assessing energy efficiency instrument mixes: the importance of comprehensiveness

2.1. Existing strands of literature on policy mixes

So far, the majority of studies looking at the role of EU policy for innovation and energy efficiency have focused on single policy instruments and their role in achieving a greater uptake of energy efficient technologies. In reality, the EU itself and also most EU Member States employ a set of different energy efficiency policies rather than just one single instrument [13,12,23]. The idea that one policy instrument is used to address one particular policy goal (known as the Tinbergen rule) has long been discredited. Instead it is increasingly accepted in the academic literature that “[p]olicies increasingly come in complex packages and understanding the nature of design criteria for such portfolios of policies and instruments is increasingly important” [22; p. 1]. Energy policy is probably the domain most studied from a policy mix perspective [53], with a main focus on emissions trading schemes and renewable energy policies (e.g. [24,25,54]) and, to a lesser extent, energy efficiency [13,12]. However, even within this policy domain, papers analysing the instrument mix rather than individual instruments are scarce.

One strand of this policy mix research (mainly within economics) has focussed on interactions between two or more instruments. The main concern in this literature is that using several instruments to achieve the same policy objective, these instruments should be mutually supportive rather than undermining each other. Especially for targeting environmental problems it has been pointed out early on that a better approach than focussing on single instruments is to use combinations of instruments because no single instrument is “sufficiently flexible and resilient to be able to successfully address all environmental problems in all contexts” [19; p. 49]. Instead, good policy making will “seek to harness the strengths of individual mechanisms while compensating for their weaknesses by the use of additional instruments” [19; p. 49]. In their seminal work, these authors have developed typologies of different kinds of instrument mixes: (1) mixes that are inherently complementary; (2) mixes that are inherently incompatible; (3) mixes that are complementary if sequenced; and (4) mixes whose complementarity or otherwise is essentially context specific. Which instrument types can be used together and are seen inherently compatible or incompatible depends of the types of policy instruments, but its ex ante assessment needs to be interpreted with caution due to the context specificity of instrument interactions. Empirical analyses of the combined effects of policy instruments often focus on a small number of instruments or commonly just two instruments (e.g. [27,12,28]). However, most of these analyses are static and focus on interactions at one point in time, thereby making them less relevant when thinking about policy mixes for long term transformative change in the context of energy transitions.

Another strand of policy mix research focuses on the temporal dynamics of policy mixes. In the policy studies literature, the understanding of policy mixes goes beyond instrument interactions and has been defined as “complex arrangements of multiple goals and means which, in many cases, have developed incrementally over many years” [28; p. 395]. This literature starts from the observation that in most cases policy makers do not start with a ‘blank slate’ when developing policy but that any new policy goal or instrument introduced normally joins a patchwork of existing policy goals and instruments. This literature takes into account the empirical fact that most policy mixes evolve in a rather haphazard way rather than being consciously ‘designed’ by policy makers [8]. Of course, policy making processes are majorly influenced by politics, which also means that a priori there are no unambiguously ‘good’ mixes and that analysis should focus on the actors, instruments, institutions and interactions which shape public policy [6]. Nevertheless, research has analytically distinguished between different kinds of processes through which additional goals and instruments are added to the mix, depending on whether the goals are coherent (meaning that they can be simultaneously achieved without trade-offs) and whether instruments are consistent (meaning that they do not counteract each other) with what is already in place (e.g. see [29,8]). The argument is that incoherent and inconsistent policy mixes are unlikely to achieve policy goals. While initially the policy design literature argued for the wholesale replacement of existing arrangements through new policy packages, more recently it has been argued that also strategic 'policy patching' (in the same way as software patches fix issues) can be a suitable strategy to improve the coherence and consistency of the mix [8]. Recent research has applied this framework to the evolution of 'real world' rather than 'ideal' policy mixes in the cases of building related energy efficiency policies in Finland and the UK. The research found that both countries have increasingly complex policy mixes, encompassing a variety of goals and instruments and making use of a variety of different types of instruments, creating challenges for both the design and evaluation of these mixes but also that there was a lot of 'churn', partly for political reasons [13]. Policy design scholars are also interested in other policy mix characteristics such as the 'goodness of fit' (i.e. policy mixes which match their governance context) [23; p. 175].

The relevance of such characteristics for evaluating the impact of policy mixes on technological change in energy systems and on sustainability transitions more broadly has been stressed by Rogge and Reichardt [4]. Yet, as point out by these authors, different literatures have used various, often conflicting definitions of such characteristics, particularly when it comes to consistency and coherence (see wide range of definitions in the Annex of Rogge and Reichardt [15]. Such ambiguity in terminology renders a comparison of different studies and interdisciplinary dialogue difficult. Therefore, in our analysis we adopt the terminology proposed by Rogge and Reichardt [4] which differentiates between the consistency of policy mix strategy and instruments and the coherence of policy processes. More importantly, however, we follow their call for a broader consideration of policy mix characteristics as it may ultimately be these characteristics which help explain the effectiveness and efficiency of policy mixes. First empirical studies, albeit mostly qualitative in nature, have particularly stressed the importance of policy mix credibility and consistency for stimulating low-carbon innovation, but have also pointed to the relevance of coherence and comprehensiveness [16].

The comprehensiveness of policies has long been argued to be a relevant success factor of environmental and energy policies [30,58]. However, in these studies, comprehensiveness remained a loosely defined concept. Drawing on conceptualisations of comprehensiveness in the field of marketing and environmental management systems [52,56], Rogge and Reichardt [36; p. 1627] concretised policy mix comprehensiveness as a characteristic which "captures how extensive and exhaustive its elements are". While they also include the degree to which policy making and implementation are based on extensive decision-making, in this paper we focus on the comprehensiveness of the instrument mix. In line with Rogge and Reichardt [4] we argue that instrument mix comprehensiveness can be assessed according to the degree to which it considers relevant failures and barriers [5] ([57,59]). More specifically, it can be captured by assessing if the instrument mix includes technology push, demand pull and systemic instruments [17]. A first attempt to quantitatively operationalize the comprehensiveness of instrument mixes (and other policy mix characteristics) has been made by Costantini et al. [18] in their patent-based econometric analysis of energy efficiency innovation in the residential sector of 23 OECD countries. Regarding the comprehensiveness of the instrument mix they find that a greater number of instruments in the mix enhances innovation activities in energy efficiency. However, they also identify a threshold effect indicating that an ever-increasing number of policy instruments at some point reduces the effectiveness of the policy mix, e.g. as a result of negative interactions resulting from policy fragmentation.

In this paper, we add to these early contributions on assessing the comprehensiveness of instrument mixes by focusing on technology/technological specificity and target sector(s) as two additional dimensions of instrument mix comprehensiveness [15]. In addition, we also pay explicit attention to the instrument types covered, but follow a more differentiated instrument typology than past studies which have only differentiated between technology push, demand pull and systemic instruments. We argue that the more ambitious a given policy strategy, the greater the need for instrument mixes which cover a broad spectrum of solutions rather than low-hanging fruits only, different types of instruments rather than only economic ones, and a wide range of sectors rather than mainly focusing on electricity generation while neglecting other sectors, such as transport or buildings.

In the next section we develop a novel conceptualisation of comprehensiveness in the context of ambitious energy transitions.

2.2. The need for comprehensive energy efficiency instrument mixes in the context of ambitious energy transitions

There is an economic rationale for implementing those energy efficient solutions that are highly cost-effective first, before investments are made in other, more expensive low-carbon options [31]. Those so called 'low hanging fruits' tend to be characterised by relatively low cost and technological simplicity. However, given the scale of the transition required simply 'picking the low-hanging fruits' is insufficient. For example, an analysis of the EU's building stock shows that focusing only on 'shallow' renovations will miss the EU's 2050 climate objectives by a wide margin [32].

There are also risks of lock-in effects or, more precisely, lock-out effects when focusing primarily on low-cost technologies that are easy to install. Lock-in can be caused by various factors. First, the required changes for deeper energy performance improvements at a later stage might be physically very difficult to achieve (for example when a specific type of fossil fuel-based heating system is installed). Also, whilst it may be physically possible to upgrade, the costs of doing so may render it uneconomic [33]. Furthermore, those responsible for making decisions about energy efficiency improvements may be hesitant to accept another phase of disruption after already having had relatively simple and low-cost technologies installed. For example, building owners may not be supportive of additional and deeper energy efficiency improvements once the low-cost options have been installed [34]. Also, if several technical measures with different payback periods are 'packaged' it is likely to be easier to persuade asset owners to invest in more costly technologies compared to when considering them individually [22]. Given that most buildings can be expected to be retrofitted only once within a 40-year cycle [35], it seems pertinent to exploit the time window during which this takes place and encourage deeper, more complex retrofits. However, it is also important to appreciate that in some instances, for example when capital availability is a constraint and disruption due to building works needs to be spread over time, a staged approach to energy efficiency improvements may be more appropriate [22] and can lead to the same result if the staging is considered carefully. Finally, promoting more costly and complex niche technology also implies incentives for innovation and this results in cost-reductions in the future through learning-by-doing that can ultimately lead to 'industrialisation' of more complex energy efficiency technologies [36].

Both the need for larger energy efficiency improvements in order to meet the long-term climate targets and the risk of locking out highly efficient and innovative solutions means that instrument mixes must provide support for more capital-intensive and complex technologies too. This does not mean that instruments promoting relatively low-cost single measure energy efficiency improvements are not needed. However, we argue that a comprehensive instrument mix needs to cover the full range of technologies regarding complexity and costs to enable both deep, one-off improvements and more complex (and potentially staged) solutions to improving energy efficiency. This will also result in cost reductions through economies of scale and learning-by-doing [37].

While the examples given above refer to the building sector, the area with the highest potential for energy efficiency improvements [38], the same logic applies to other sectors. When considering how instrument mixes can (and should) support energy efficiency in the context of an energy transition it is therefore important to understand the differences between sectors and, in particular, the degree of comprehensiveness within specific sectors.

Furthermore, the degree to which different instrument types currently support more complex and costly solutions provides insights into how to design future instrument mixes aimed at deeper energy efficiency improvements. Potentially, some instrument types may be more suitable for this than others. Therefore, those involved in designing instrument mixes need to develop an understanding of the importance of their comprehensiveness regarding technologies, sectors and instrument types.

Building on the discussion above, in the following subsections we develop the analytical framework used for the subsequent empirical assessment of energy efficiency instrument mixes. The main building blocks of the framework we apply in this paper are a) technological specificity, b) types of policy instruments, and c) sector specificity.

2.2.1. Technological specificity: technology costs and technology complexity

An important concept for the understanding of the role of instrument mixes for energy efficiency improvements is to what extent certain instruments are technology neutral or technology specific. An extensive discussion on policy approaches and the extent to which technology-specificity is desirable can be found in the economic literature. Many economists agree that 'picking winners' is always a second-best approach and that ideally market-based instruments provide the context in which the winners are identified through a search process. A classic example of a policy instrument that picks winners are technology-specific subsidies (e.g. a grant for more energy efficiency windows or a feed-in tariff for photovoltaics). Well-known policy instruments that are technological neutral include Pigouvian taxes (e.g. a carbon tax) and emissions trading schemes (e.g. EU Emissions Trading System).

Whilst in theory market-based instruments deliver the same outcome at lower cost, there is now a growing recognition that relying on technological neutral policy instruments is likely to be insufficient for achieving an ambitious and wide-ranging energy transition [39], partly because such instruments are not designed and implemented in a politically neutral space. Policy instruments that are technological neutral are often not providing sufficient stimulus for accelerated technological diffusion – environmental taxes remain relatively weak [40] and emissions trading system do not set emissions caps that require and encourage substantial uptake of energy efficient technologies [41]. Of course, such deficiencies of technology-neutral policy instruments can and should be addressed. Given the many political obstacles it is questionable whether this can be achieved easily. Much of the transitions literature argues that technology-specific policy instruments are needed [39,42]. However, market-based instruments are not by definition technological neutral and recent analysis by Rosenow et al. [43] shows that market-based instruments for energy efficiency such as Energy Efficiency Obligations and auctions can be designed in such a way that they do support specific technology types and deeper energy performance improvements.

Recognising the limitations of technologically neutral policy instruments and the scale of the energy transition required for meeting the targets set out in the Paris Agreement, so-called 'second-best' policy instruments are indispensable. In reality, countries across the world have deployed a range of highly technology-specific policy instruments. Therefore, the first building block of our framework of comprehensiveness is to assess to what extent the instrument mix is technology-specific. We also distinguish between the cost of technologies and their complexity to further classify technology specific policy instruments. In the methodology section both technology cost and complexity are defined more precisely in the way the two parameters have been applied in this paper.

2.2.2. Types of policy instruments

The policy mix literature reviewed above is clear that instrument mixes should encompass different types of instruments in order to be effective as different instruments have different strengths and weaknesses and can therefore complement each other (e.g. [26]). Importantly the early policy design literature often argued for implementing the least intrusive policy measures first and then increasing the level of coercion if needed to achieve policy targets. However, more recently Howlett and Rayner have argued that "rather than assuming that a choice must be made between only a few alternatives such as regulation versus market tools" (2013, p. 175), policy makers are encouraged to use the full range of possible instruments. This is especially important in the context of sustainability transitions in which instrument mixes need to address a whole range of market, system and institutional failures [4]. There is great variance of policy instrument types and whether or not they support specific technologies or are technologically neutral. Therefore, the second building block of our analytical framework for assessing the comprehensiveness of instrument mixes analyses the types of policy instruments being utilised.

2.2.3. Sector specificity

Energy is used through many different processes which is one of the difficulties of sufficiently targeting energy efficiency instrument mixes. In this context, Nilsson et al. [44] has argued that the design of simple and comprehensive instrument mixes for an energy efficiency transition is complicated by the variety and complexity of end-users of energy. For example, energy efficiency opportunities in the industry sector cover more than thousand different energy efficiency technologies due to the complexity of industrial processes and variety of sectors, whereas in the residential buildings sector the number of measures is far lower with fewer than 10 common interventions providing most of the savings. It is therefore important to broadly distinguish between instruments targeted at different sectors such as residential, service (including public), industry, and transport as well as those that are cross-cutting instruments and address several or all sectors in order to assess the comprehensiveness of the instrument mix. A sector specific analysis may reveal important gaps in the instrument mix. This is important since the ambitious energy efficiency targets mean that each of these sectors have a significant contribution to make [38]. To what extent certain sectors are targeted by policy instruments therefore is the third building block of our proposed instrument mix comprehensiveness framework.

Whilst comprehensiveness may also be assessed through the lens of additional dimensions, we argue that our analytical framework covers three key aspects and offers an approach that can be applied relatively easily to existing instrument mixes within the energy efficiency policy domain. The next section will elaborate our methodology and how we operationalised key concepts.

3. Methodology

As described above, the focus of this paper is on national energy efficiency policies which have been notified by EU Member States to the European Commission as part of their transposition of the EU Energy Efficiency Directive, Article 7 (for a more detailed explanation of the policy background, see Section 4). This means that our analysis does not encompass all forms of efficiency policy. Policies which were already mandatory within the EU, e.g. energy labelling, minimum standards for buildings, are not included as they are not additional and the Directive excludes those from being used for the purpose of Article 7. Neither are policies which occur in the early stages of technology innovation, e.g. RD & D support. The focus is on national (and sub-national) policies which affect the uptake of energy efficiency measures already available on the market.

Data on instrument mixes in selected EU Member States was obtained from national experts from Austria, Belgium, Bulgaria, Denmark, Estonia, France, Germany, Greece, Italy, Netherlands, Poland, Spain, Sweden and the United Kingdom. All of the experts were part of the ENSPOL project, which was funded by the European Commission. The full list of involved institutions can be found on the ENSPOL project website (http://enspol.euhttp://enspol.eu). Those experts led extensive research on how specific EU countries implement Article 7 of the EU Energy Efficiency Directive and have deep knowledge about the instrument mix employed in those countries. The Member States analysed were Austria, Belgium, Bulgaria, Denmark, Estonia, France, Germany, Greece, Italy, Netherlands, Poland, Spain, Sweden and the United Kingdom. The rationale for their selection was to cover a wide range of different regulatory traditions and policy approaches whilst keeping the sample size manageable. In order to limit the scope of the analysis for each country, we selected the 10 most important energy efficiency policy instruments (importance was defined in terms of their expected energy savings provided in the Article 7 notifications on the European Commission's website).

Each national expert provided information on each of those 10 policy instruments on our comprehensiveness criteria which were explained in more detail above.

- **Instrument type**: The Energy Efficiency Directive allows for the use of any instrument (as so-called alternative measures) that results in end-use savings equivalent to the target defined by Article 7. It provides a typology of instruments that can be considered for implementation, which has also been used for the classification in this paper (Table 1).
- **Sector**: We differentiated between instruments focusing on the residential, service (including public), industry, and transport sectors as well as those that are cross-cutting instruments and address several or all sectors.
- **Technological specificity:** In our analysis we have chosen two dimensions to assess technological specificity:
  a) **Cost of supported technology**: Cost includes all cost involved (capital cost and ongoing cost if applicable) regardless of how the cost may be shared across different actors. The cost categories are relative and refer to how a specific energy efficiency technology/ measure relates to other energy efficiency technologies/measures. We used a simple 1–5 scale with 1 representing technologies with low cost and 5 those with high cost. Scoring was performed by the country experts.
  b) **Complexity of supported technology**: Through expert judgement by the country experts we categorised the complexity of the technologies using a simple scale of 1 (low complexity) to 5 (high complexity). Complexity refers not only to the technology itself but also the installation process. For example, replacing an electric motor in a factory is a relatively simple improvement where both the technology and the installation process is simple. A whole-house retrofit to Passivhaus standard involves multiple technologies interacting with each other and a complex installation process where different trades get involved at different stages.

The full dataset derived from this exercise is expansive and cannot be presented in this paper due to space constraints. However, the data used can be found in the annex of a final report of the ENSPOL project [45].

4. The case of energy efficiency policy in europe: background

The empirical analysis of this paper focuses on Article 7 of the EU Energy Efficiency Directive (EED). The EED establishes a framework of measures to ensure the achievement of the EU's 20% energy savings target by 2020 (EP 2012). Previous EU policies seek either to set common frameworks for energy efficiency policy in Member States, e.g. the Energy Performance of Buildings Directive (EPBD) and the Energy Services Directive (ESD), or to use EU competencies in trade policy to establish common labels and standards, e.g. through the Ecodesign Directive. Together these have increasingly influenced national energy efficiency policies of EU Member States.

The EED (2012/27/EU) was designed to bring the European Union back on track to achieve the 20% energy consumption reduction target and is one of key steps identified by the Communication on the Energy Efficiency Plan 2011 and the Roadmap to 2025. Previous analysis by the European Commission has shown that existing energy efficiency instruments would not deliver the 20% target by 2020 and leave a significant gap of more than half of the required reduction [46].

The Directive puts in place several important provisions to be implemented by Member States including the requirement to establish binding national energy efficiency targets (Article 3), national building energy efficiency strategies (Article 4), a requirement to renovate 3% of public sector buildings each year (Articles 5 and 6), the need to establish energy efficiency obligation schemes (Article 7), and provisions for auditing and metering (Articles 8–12). Instead of evaluating the impact of the whole Directive (which would be a herculean task), we focus on probably the most important (in terms of energy savings) Article of the Directive (Article 7), which requires Member States to

Table 1
Definition of instrument types.

Instrument type	Definition
Energy Efficiency Obligations (EEOs)	EEOs oblige energy suppliers and/or distributors to deliver a specified amount of end-use energy savings within a defined period of time.
Energy efficiency national fund	Even though many MSs operate a national fund for financing energy efficiency measure, in this context it means a fund where obligated parties can make an annual financial contribution to fulfil their obligation under Article 7 as defined in Article 20(6).
Energy or CO_2 taxes	A levy on the energy and/or carbon content of fuels above minimum EU-requirements that – by increasing the price of the fuels-incentivises fuel saving. Financial stimuli to energy efficiency investments through the taxation system (e.g. tax rebates for building renovation) are included in the financing and fiscal incentive policy group.
Financing scheme or fiscal incentive	Such schemes provide monetary support from public sources that are allocated either on the basis of application (e.g. applying for a grant under a renovation support scheme) or induce energy saving actions automatically (e.g. automatic eligibility to tax concession when purchasing an electric vehicle).
Regulation or voluntary agreements	Voluntary agreements are typically agreements by a sector – or group of similar actors- with public authorities in which they commit to a) reduce end-use energy consumption over time, b) design and implement an energy efficiency plan, or c) apply specific energy efficient technologies. Regulations – in this context – are obligatory and legally binding measures that do not belong in any of the other categories.
Standards and norms	These administrative measures aim at setting minimum energy efficiency requirement of products and services in addition to mandatory EU requirements.
Energy labelling schemes	Energy labels provide easy-to-understand energy use information of products that facilitate energy-conscious consumer choices.
Training and education	Educational actions that results in the use of efficient technologies or behavioural changes reducing end use consumption.
Other instruments	This category comprises any other instruments that do not fit with the main categories of policy instruments.

implement Energy Efficiency Obligations and/or alternative policy instruments in order to reach a reduction in final energy use of 1.5% per year (EP 2012). Article 7 is expected to deliver more than half of the required energy savings of the 20% reduction target and is therefore the most important component of the EED in terms of its expected contribution [46]. The legislative proposals in the European Commission's recently released 'Winter Package' (also branded as 'Clean Energy for All' proposals) (EC 2016) extend Article 7 beyond 2020 at similar ambition levels [47].

Article 7 of the EED requires Member States to establish either energy efficiency obligations (EEOs) or alternative policy measures, to achieve new energy savings each year, over the 2014–2020 period, amounting to 1.5% of the baseline annual energy sales to final customers. In reality the average energy savings are closer to 0.75% because Article 7 allows Member States a) to exclude a range of energy end uses when calculating their targets (transport, energy for own use etc.) and b) a number of exemptions up to a maximum of a 25% reduction of the energy savings target. Most Member States made use of both options [23].

Member States have a large degree of freedom when it comes to designing the instrument mix for achieving their targets. In total, 479 policy instruments have been notified to the European Commission of which 75% are existing instruments [48]. Most of those policies are focusing on the diffusion of energy efficient technologies as it is not feasible to calculate energy savings from R & D policies under the rules of the EED. Overall, the instruments notified to the European Commission are a good reflection of the instruments used for the diffusion of energy efficient technologies except for existing EU-wide rules such as the Ecodesign Directive and minimum taxation levels. This means that the empirical basis for the analysis does not cover all instruments targeting energy efficiency but most of them.

5. Results and discussion

In this section we present and discuss the results of our analysis of the comprehensiveness of the energy efficiency instrument mixes of selected EU Member States in terms of the frequency of using different instrument types within the different target sectors as well as their technology specificity in terms of complexity and cost. A descriptive presentation of the instrument mixes found in the different sectors is followed by an analysis of the technology-specificity of specific instrument types in each of the defined sectors and a discussion of these results.

5.1. Comprehensiveness according to use of instrument types by sector

Below the instrument mix is described by sector regarding the frequency of the use of different instrument types. A high frequency does not, however, automatically translate into a large amount of energy savings delivered but is rather a measure of how much attention policy makers pay to which type of instrument (so in a sense their instrument preferences). Analysis by Rosenow et al. [23] provides an assessment of the contribution from different instrument types to the overall energy savings. Here, the focus is not on the amount of savings but on the frequency of particular measures.

Fig. 1 provides an overview of the most commonly used policy instrument types for the purpose of complying with Article 7 of the Energy Efficiency Directive across the 14 Member States analysed. In the residential sector by far the most frequently used instrument is grants (33%) followed by regulations (17%), loans (16%) and energy efficiency obligations (11%). The non-residential sector is very similar with the main exception that no voluntary agreements were included in the sample. In the industry sector grants play a less important role (although still being the most frequently used instrument) and the number of instrument types is more evenly distributed. In transport regulations and loans are not used by the Member States analysed for the purpose of complying with Article 7 of the Energy Efficiency Directive. Not surprisingly, the cross-cutting category consists primarily of energy and CO2 taxes and energy efficiency obligations which often target a wide range of sectors.

Grants are the most popular instrument in all sectors, which may be due to the fact that they are a long-established policy mechanism that is relatively simple to design and administer. However, in terms of the specific instrument mix in each of the sectors, policy makers in the analysed Member States make good use of the full 'toolbox' proposed by the EU Commission. This is note-worthy as it shows the orthodoxy of the Tinbergen rule no longer seems to be dominant (at least in energy efficiency) policy making. From a comprehensiveness perspective, this is encouraging as it allows for different instrument types with different strengths and weaknesses to complement each other (cf. [26]). This finding also shows that policy makers have moved beyond an earlier recommendation in the policy design literature to start from the least intrusive measures (such as information provision or voluntary agreements) and only later increase the level of coercion if needed (e.g. through regulation) (cf; [8]) which is important in the context of very ambitious policy targets which arguable need both 'sticks and carrots'. This also confirms similar findings of a recent detailed analysis of building related energy efficiency policies in Finland and the UK [13]. What this analysis, however, also showed was that there was significant variation across these two Member States in terms of the use of instrument types (e.g. in Finland voluntary measures were much more prevalent than in the UK). While this is beyond the scope of this paper, future research should focus on the reasons for this divergence by looking at a wider range of EU Member States. Differing policy traditions as well as country-specific problems or circumstances, rather than the effectiveness of the instrument type per se, may do much to explain such differences in the frequency of using certain types of instruments.

5.2. Comprehensiveness according to technology-specificity of the instrument mix

Based on the data provided by the experts on the complexity and cost of the technologies supported by the policy instruments the focus of different instrument types can be compared. The results of this analysis by sector is presented below before we analyse the findings across all sectors. The position on the charts shows for which cost and complexity segment a policy instrument type is primarily used based on the sample of the 14 Member States analysed. The diameter of the bubbles indicates the frequency with which the policy instrument was used across the sample.

5.2.1. Residential buildings sector

Most policy instruments in the residential sector focus on the medium cost and medium complexity segment. As expected, loans clearly target the higher cost and complexity measures. There are no other policy instrument types supporting technologies with a higher than medium complexity and cost, with most instruments being located in the medium cost and complexity category. Surprisingly, information measures target low cost but medium complexity measures, partly due to the inclusion of smart meters in this policy instrument category which are more complex than other information measures (Fig. 2).

Going forward, it is clear that significant investment is required in the building sector to achieve a substantial reduction in energy demand. Relying primarily on grant programmes is unlikely to be sustainable in the long-term because publicly-funded grants have relatively low leverage ratios (the degree to which they mobilise additional private finance). Dedicated loans instead have much higher leverage ratios of 4–10 [49]. Thus, in future years, a shift from grants towards loans appears to be required.

5.2.2. Non-residential buildings sector

The focus of the policy instruments used in the non-residential

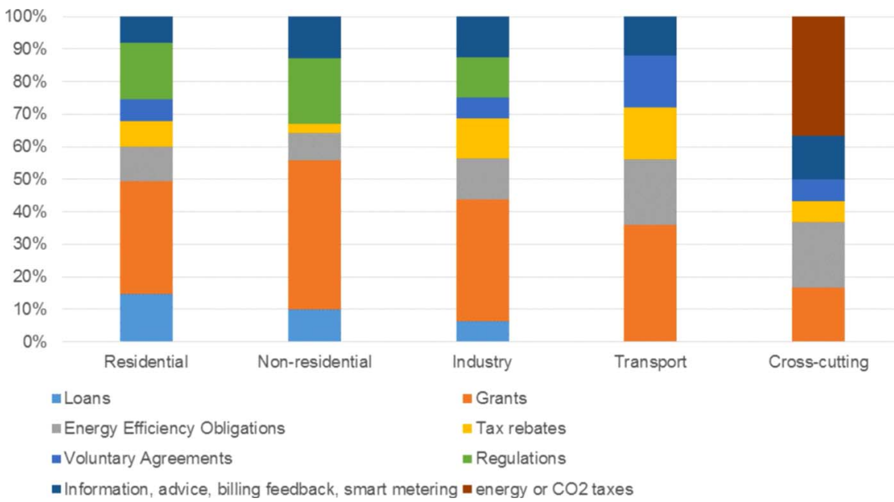

Fig. 1. Instrument mix by sector and instrument type across cases.

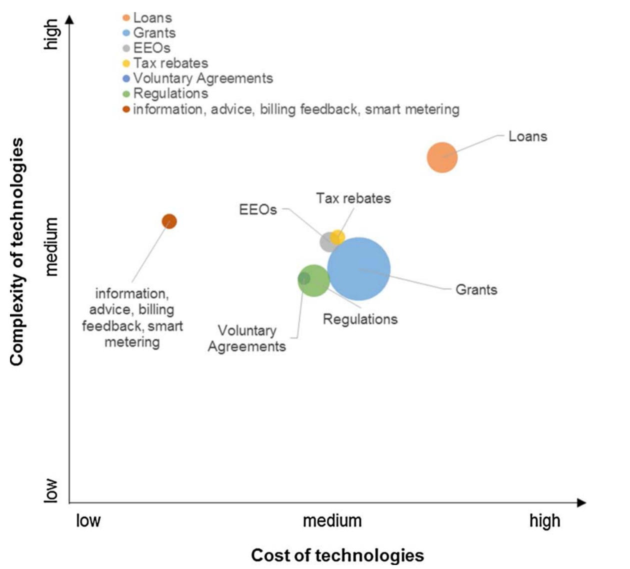

Fig. 2. Technology cost and complexity by policy instrument type for the residential sector.

sector is very similar to the residential sector in that most policy instruments focus on the medium cost and complexity segment. However, loans are used to target more complex and costly technologies compared to the residential sector (Fig. 3).

The strong reliance on grant programmes in the non-residential buildings sector is concerning for the same reasons as outlined for the residential buildings sector.

5.2.3. Industry sector

The number of policy instruments used in the industry sector is significantly lower than in the buildings sector (about 1/3). Overall, policy instruments used in the industry sector focus on more complex and capital-intensive technologies compared to the other sectors.

Industry is the only sector where loans are not used for the most expensive measures. Voluntary agreements target more costly measures than regulation which is expected as regulation defines the floor whereas voluntary agreements go beyond compliance (Fig. 4).

It seems that in the industry sector instruments provide more support for costly and complex technologies than in the buildings sector. This is encouraging, although the majority of programmes are classified as grant programmes as well.

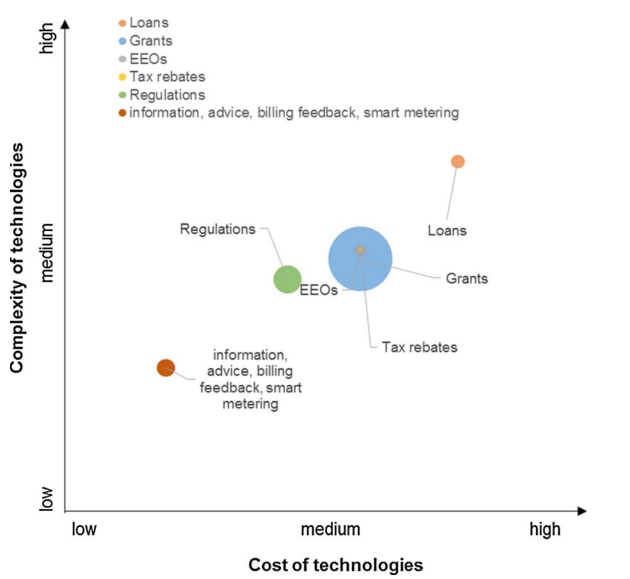

Fig. 3. Technology cost and complexity by policy instrument type for the non-residential sector.

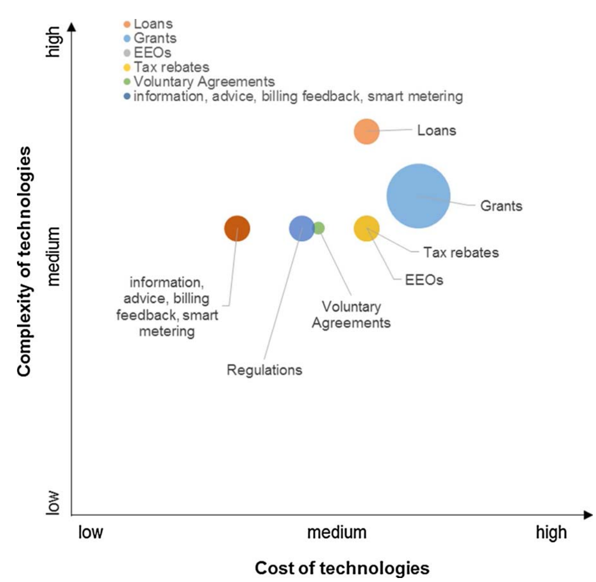

Fig. 4. Technology cost and complexity by policy instrument type for the industry sector.

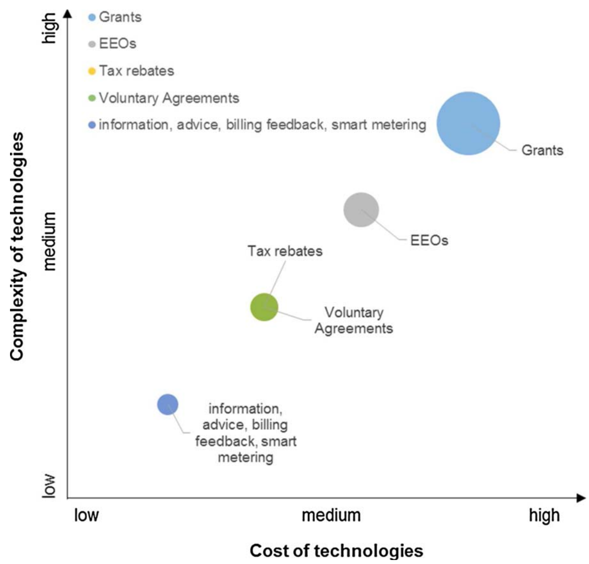

Fig. 5. Technology cost and complexity by policy instrument type for the transport sector.

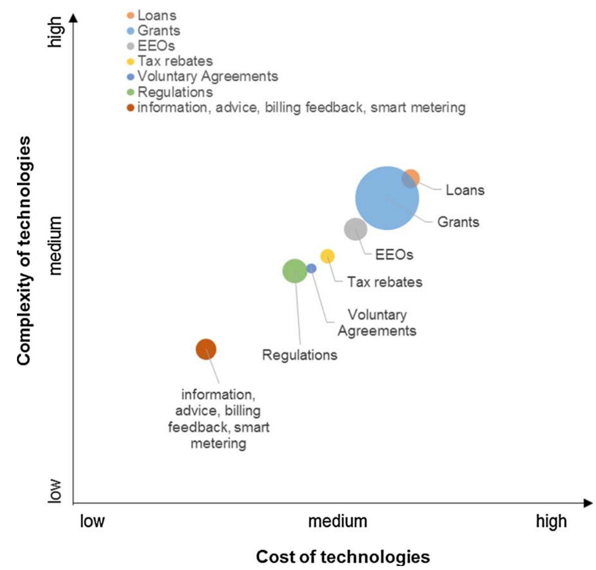

Fig. 6. Technology cost and complexity by policy instrument type for all sectors.

5.2.4. Transport sector

The transport sector can be characterized by a relatively small number of policy instruments and also policy instrument types (there are no loans and energy taxes). EU emission performance standards for new passenger cars and new light commercial vehicles are excluded from the scope of Article 7. Also, policies that do not focus primarily on end-use energy savings are excluded from Article 7, meaning that policies such as electrifying the rail system are not eligible.

The order of policy instruments does not diverge from the patterns observed across the other sectors with increasing complexity and cost from information measures to grants.

The previously noticed relationship between cost and complexity is most profound in the transport sector with a clear linear correlation (Fig. 5).

The transport sector is somewhat different in that it only provides a very small share of the total energy savings notified by Member States [12]. As mentioned above, many policy instruments targeting this sector are outside of the scope of Article 7. Transport is also different in that retrospective upgrades of vehicles commonly not possible as is the case in a building or factory.

5.2.5. Analysis of instrument for all sectors combined

Across all sectors, the overall analysis shows (see Fig. 6) that loans focus on the more complex and costly technologies which is in line with the evidence on loans being able to achieve higher leverage effects than direct subsidies of energy efficiency measures [50]. Loans are closely followed by grants and EEOs which are firmly targeting technologies of medium complexity and cost. Tax rebates appear to focus on low to medium cost measures which is in line with the evidence from other tax rebate programmes in the world [50]. Voluntary agreements and agreements target a similar cost and complexity segment with regulations supporting slightly cheaper and less complex measures. As expected, information, advice, billing feedback and smart metering are located within the low cost and low complexity category. However, this policy instrument indirectly also helps facilitate the implementation of the other policy instruments that are focused on more costly and complex technologies.

The data shows that none of the instrument types target specifically highly complex and capital-intensive technologies. We argued earlier in this paper that a comprehensive instrument mix in the area of energy efficiency needs to cover the full range of technologies regarding complexity and costs. The limited focus on more complex and costly technologies indicates that further policy development is required in order to achieve deeper energy efficiency improvements across all sectors. This may be partly a function of the focus on existing commercialised technologies (rather than innovative technologies or technology combinations) which characterises Article 7 policies. However, it also indicates a possible gap in the instrument mix, whereby the next set of mass market efficiency measures are not being sufficiently supported or incentivised.

Notably, there are also few policies characterised as focussing on low cost/low complexity measures – in fact, only information, advice and related policies are classified in this way. This may be a function of the difficulty of verifying and accounting for savings from such policies, leading to their exclusion from Article 7 national submissions or policy makers do not see a need for government intervention to support such technologies. While deeper energy efficiency improvements are certainly needed to achieve significant reductions in energy demand, it is equally important to support lower cost technologies and policy makers need to capture those energy efficiency opportunities in the instrument mix.

There are two principal differences between the instrument mixes employed in the different sectors: First, the number of instruments differs significantly between the sectors – the number of instruments in the industry and transport sectors is much smaller than in the buildings sectors. Second, in the industry sector there are no instruments focusing on technologies with lower capital costs.

This can be explained by various factors. The potential for energy savings is much smaller in the industry and transport sectors compared to the buildings sectors which may explain why policy makers focus more attention on the buildings sector. A recent study [38] investigating the energy efficiency potential across Europe in the different sectors estimates that under an ambitious energy efficiency policy framework (high policy intensity scenario) in the buildings sectors energy savings of 26% can be achieved compared to projected energy demand in 2030. In contrast, the potential in the industry and transport sector is estimated to be just 12% and 13% respectively. The reason for the relatively low potential in the industry sector and particular in energy intensive processes is that many energy efficiency improvements have been achieved in the past driven by high energy cost. In the transport sector, long lifetimes of ships, trains and aircraft limit the potential for energy efficiency improvements compared to passenger cars with shorter lifetimes [38].

A reason for the focus of instruments operating in the industry sector on medium to high cost and technological complexity of energy efficiency improvements is that the industry sector is inherently more complex regarding energy efficiency improvements, both in terms of the number of potential measures which can be in the thousands as well as the complexity of the technologies itself. Many energy efficiency improvements are bespoke to a particular sub-sector and cannot be standardized easily as is the case in the buildings sector. This complexity of end uses is well known in the literature (e.g. [44]) and means that policy makers are struggling to support non-standard energy efficiency measures. Of course in principle a very high carbon or energy tax can address this problem without needing to have dedicated support for different measures, but since such high taxes are politically difficult because of concerns about industrial competitiveness, this is unlikely to offer a solution.

What these results mean in terms of comprehensiveness of the existing instrument mixes is that while they are addressing all relevant sectors in some ways, more attention to the industrial and transport sectors may be required. In particular, the instrument mix for the industry sector is least comprehensive according to our analysis as it contains fewer instruments overall and covers fewer types of technology measures (no lower cost measures) which may be problematic given the energy efficiency gap between theoretical cost-effective reduction potentials and their limited take up. This is particularly important since the share of energy use of transport and industry across the EU as a whole is very high (33.2% of EU-28 final energy consumption is for transport and 25.9% for industry, according to 2015 Eurostat data) so without significant changes in these sectors, achieving longer term carbon and energy deduction target is unrealistic. However, focussing on the building sector reduction potential in the short term (to achieve the 2020 target) may be a useful strategy as long as more radical, medium to longer term options are also simultaneously pursued. This may be done through dedicated public R & D policies which were beyond the scope of analysis presented in this paper.

6. Conclusions

In this paper we contributed to an ongoing academic discussion about the need for policy mixes to stimulate energy transitions. Much of the existing work has focused on the combination of various instruments in instrument mixes and their interactions, as well as their evolution over time in terms of consistency and coherence. Our paper contributes to the greater attention of such policy mix characteristics by advancing the measurement and analysis of the comprehensiveness of instrument mixes. Because of the importance of energy efficiency for meeting EU policy objectives we focussed on this policy domain and made a case for broadening existing conceptualisations of comprehensiveness. Specifically, we argued that in the context of energy transitions the comprehensiveness of instrument mixes in a given policy domain should be assessed regarding several dimensions, in particular, their technology specificity, instrument types utilised, and target sector (s) addressed. We argued that especially understanding the technology specificity of instruments in the mix is a precondition to designing effective instrument mixes that support the full range of low-carbon solutions needed to achieve an ambitious energy transition, including low-cost and simple energy efficiency measures as well as high-cost and complex options.

We applied this concept of instrument mix comprehensiveness to the field of energy efficiency which is critically important to achieving an energy transition in line with the pledges made in the Paris agreement. Our analysis shows that in selected EU Member States, the main focus of instruments lies on technologies characterized by relatively moderate costs and complexity. It indicates that there is a lack of policy instruments supporting deeper energy efficiency improvements, which is a problematic gap in the instrument mix which needs to be addressed if ambitious EU targets are to be met. However, adding such instruments may be costly and therefore politically contested.

We argue that our framework can also be usefully applied to other policy domains of relevance to ambitious energy transitions (e.g. renewable energy policy) where much of the current policy attention has been on the electricity sector rather than for example heat or transport and where different sets of technology specific as well as technology neutral instruments are being pursued. We also think this analysis can usefully be extended to other EU Member States as well as countries in other regions of the world.

A limitation of our analysis is that the paper focuses on instruments adopted by Member States to meet their Article 7 commitments – this excludes those instruments which are already required by other EU regulations, implying that standards and norms, energy labels and regulations are under-represented compared with their presence in national instrument mixes (cf. [13]). Also, support for the development of energy efficient solutions (e.g. RD & D policy) was not covered in our dataset. Also, in the absence of data and ex-post evaluations of instruments, the assessment of technology specificity was carried out through expert judgement rather than a more sophisticated quantitative evaluation of the instruments in the mix.

Future research should therefore identify more precisely (through ex-post analyses) the degree of comprehensiveness of the instrument mix. In particular, one focus of such studies should be the types of technologies targeted within the energy efficiency space as this becomes increasingly important given the diversity of national approaches to delivering EU energy savings targets. Another interesting line of research is to compare the comprehensiveness of instrument mixes across different countries (or different governance levels). Such comparative work could help explain key similarities and differences, thereby potentially identifying generic (e.g. technology or sector related factors) as well as country specific factors (e.g. national policy traditions or policy styles) (e.g. see [51]) which influence the comprehensiveness of instrument mixes. Finally, future research should pay greater attention to the politics of designing instrument mixes which may be another key factor determining their comprehensiveness.

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